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W MASS

The W -mass listed here corresponds to the mass parameter in a Breit-Wigner distribution with mass-dependent width. To obtain the world average, common systematic uncertainties between experiments are properly taken into account. The LEP-2 average W mass based on published results is 80.376 ± 0.033 GeV [SCHAEEL 13A]. The combined Tevatron data yields an average W mass of 80.387 ± 0.016 GeV [AALTONEN 13N].

OUR FIT uses these average LEP and Tevatron mass values and combines them assuming no correlations.

<u>VALUE (GeV)</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
80.385 ± 0.015 OUR FIT				
80.387 ± 0.019	1095k	1 AALTONEN	12E CDF	$E_{\text{cm}}^{p\bar{p}} = 1.96$ TeV
80.367 ± 0.026	1677k	2 ABAZOV	12F D0	$E_{\text{cm}}^{p\bar{p}} = 1.96$ TeV
80.401 ± 0.043	500k	3 ABAZOV	09AB D0	$E_{\text{cm}}^{p\bar{p}} = 1.96$ TeV
80.336 ± 0.055 ± 0.039	10.3k	4 ABDALLAH	08A DLPH	$E_{\text{cm}}^{e^+e^-} = 161\text{--}209$ GeV
80.415 ± 0.042 ± 0.031	11830	5 ABBIENDI	06 OPAL	$E_{\text{cm}}^{e^+e^-} = 170\text{--}209$ GeV
80.270 ± 0.046 ± 0.031	9909	6 ACHARD	06 L3	$E_{\text{cm}}^{e^+e^-} = 161\text{--}209$ GeV
80.440 ± 0.043 ± 0.027	8692	7 SCHAEEL	06 ALEP	$E_{\text{cm}}^{e^+e^-} = 161\text{--}209$ GeV
80.483 ± 0.084	49247	8 ABAZOV	02D D0	$E_{\text{cm}}^{p\bar{p}} = 1.8$ TeV
80.433 ± 0.079	53841	9 AFFOLDER	01E CDF	$E_{\text{cm}}^{p\bar{p}} = 1.8$ TeV
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
80.413 ± 0.034 ± 0.034	115k	10 AALTONEN	07F CDF	$E_{\text{cm}}^{p\bar{p}} = 1.96$ TeV
82.87 ± 1.82 $\begin{smallmatrix} +0.30 \\ -0.16 \end{smallmatrix}$	1500	11 AKTAS	06 H1	$e^\pm p \rightarrow \bar{\nu}_e(\nu_e)X$, $\sqrt{s} \approx 300$ GeV
80.3 ± 2.1 ± 1.2 ± 1.0	645	12 CHEKANOV	02C ZEUS	$e^- p \rightarrow \nu_e X$, $\sqrt{s} = 318$ GeV
81.4 $\begin{smallmatrix} +2.7 \\ -2.6 \end{smallmatrix}$ ± 2.0 $\begin{smallmatrix} +3.3 \\ -3.0 \end{smallmatrix}$	1086	13 BREITWEG	00D ZEUS	$e^+ p \rightarrow \bar{\nu}_e X$, $\sqrt{s} \approx 300$ GeV
80.84 ± 0.22 ± 0.83	2065	14 ALITTI	92B UA2	See W/Z ratio below
80.79 ± 0.31 ± 0.84		15 ALITTI	90B UA2	$E_{\text{cm}}^{p\bar{p}} = 546,630$ GeV
80.0 ± 3.3 ± 2.4	22	16 ABE	89I CDF	$E_{\text{cm}}^{p\bar{p}} = 1.8$ TeV
82.7 ± 1.0 ± 2.7	149	17 ALBAJAR	89 UA1	$E_{\text{cm}}^{p\bar{p}} = 546,630$ GeV
81.8 $\begin{smallmatrix} +6.0 \\ -5.3 \end{smallmatrix}$ ± 2.6	46	18 ALBAJAR	89 UA1	$E_{\text{cm}}^{p\bar{p}} = 546,630$ GeV
89 ± 3 ± 6	32	19 ALBAJAR	89 UA1	$E_{\text{cm}}^{p\bar{p}} = 546,630$ GeV
81. ± 5.	6	ARNISON	83 UA1	$E_{\text{cm}}^{e^+e^-} = 546$ GeV
80. $\begin{smallmatrix} +10. \\ -6. \end{smallmatrix}$	4	BANNER	83B UA2	Repl. by ALITTI 90B

- ¹ AALTONEN 12E select 470k $W \rightarrow e\nu$ decays and 625k $W \rightarrow \mu\nu$ decays in 2.2 fb⁻¹ of Run-II data. The mass is determined using the transverse mass, transverse lepton momentum and transverse missing energy distributions, accounting for correlations. This result supersedes AALTONEN 07F.
- ² ABAZOV 12F select 1677k $W \rightarrow e\nu$ decays in 4.3 fb⁻¹ of Run-II data. The mass is determined using the transverse mass and transverse lepton momentum distributions, accounting for correlations.
- ³ ABAZOV 09AB study the transverse mass, transverse electron momentum, and transverse missing energy in a sample of 0.5 million $W \rightarrow e\nu$ decays selected in Run-II data. The quoted result combines all three methods, accounting for correlations.
- ⁴ ABDALLAH 08A use direct reconstruction of the kinematics of $W^+W^- \rightarrow q\bar{q}\ell\nu$ and $W^+W^- \rightarrow q\bar{q}q\bar{q}$ events for energies 172 GeV and above. The W mass was also extracted from the dependence of the WW cross section close to the production threshold and combined appropriately to obtain the final result. The systematic error includes ± 0.025 GeV due to final state interactions and ± 0.009 GeV due to LEP energy uncertainty.
- ⁵ ABBIENDI 06 use direct reconstruction of the kinematics of $W^+W^- \rightarrow q\bar{q}\ell\nu_\ell$ and $W^+W^- \rightarrow q\bar{q}q\bar{q}$ events. The result quoted here is obtained combining this mass value with the results using $W^+W^- \rightarrow \ell\nu_\ell\ell'\nu_{\ell'}$ events in the energy range 183–207 GeV (ABBIENDI 03C) and the dependence of the WW production cross-section on m_{WW} at threshold. The systematic error includes ± 0.009 GeV due to the uncertainty on the LEP beam energy.
- ⁶ ACHARD 06 use direct reconstruction of the kinematics of $W^+W^- \rightarrow q\bar{q}\ell\nu_\ell$ and $W^+W^- \rightarrow q\bar{q}q\bar{q}$ events in the C.M. energy range 189–209 GeV. The result quoted here is obtained combining this mass value with the results obtained from a direct W mass reconstruction at 172 and 183 GeV and with those from the dependence of the WW production cross-section on m_{WW} at 161 and 172 GeV (ACCIARRI 99).
- ⁷ SCHAEEL 06 use direct reconstruction of the kinematics of $W^+W^- \rightarrow q\bar{q}\ell\nu_\ell$ and $W^+W^- \rightarrow q\bar{q}q\bar{q}$ events in the C.M. energy range 183–209 GeV. The result quoted here is obtained combining this mass value with those obtained from the dependence of the W pair production cross-section on m_{WW} at 161 and 172 GeV (BARATE 97 and BARATE 97S respectively). The systematic error includes ± 0.009 GeV due to possible effects of final state interactions in the $q\bar{q}q\bar{q}$ channel and ± 0.009 GeV due to the uncertainty on the LEP beam energy.
- ⁸ ABAZOV 02D improve the measurement of the W -boson mass including $W \rightarrow e\nu_e$ events in which the electron is close to a boundary of a central electromagnetic calorimeter module. Properly combining the results obtained by fitting $m_T(W)$, $p_T(e)$, and $p_T(\nu)$, this sample provides a mass value of 80.574 ± 0.405 GeV. The value reported here is a combination of this measurement with all previous $D\bar{D}$ W -boson mass measurements.
- ⁹ AFFOLDER 01E fit the transverse mass spectrum of 30115 $W \rightarrow e\nu_e$ events ($M_{WW} = 80.473 \pm 0.065 \pm 0.092$ GeV) and of 14740 $W \rightarrow \mu\nu_\mu$ events ($M_{WW} = 80.465 \pm 0.100 \pm 0.103$ GeV) obtained in the run IB (1994-95). Combining the electron and muon results, accounting for correlated uncertainties, yields $M_{WW} = 80.470 \pm 0.089$ GeV. They combine this value with their measurement of ABE 95P reported in run IA (1992-93) to obtain the quoted value.
- ¹⁰ AALTONEN 07F obtain high purity $W \rightarrow e\nu_e$ and $W \rightarrow \mu\nu_\mu$ candidate samples totaling 63,964 and 51,128 events respectively. The W mass value quoted above is derived by simultaneously fitting the transverse mass and the lepton, and neutrino p_T distributions.
- ¹¹ AKTAS 06 fit the Q^2 dependence ($300 < Q^2 < 30,000$ GeV²) of the charged-current differential cross section with a propagator mass. The first error is experimental and the second corresponds to uncertainties due to input parameters and model assumptions.
- ¹² CHEKANOV 02C fit the Q^2 dependence ($200 < Q^2 < 60000$ GeV²) of the charged-current differential cross sections with a propagator mass fit. The last error is due to the uncertainty on the probability density functions.

- ¹³ BREITWEG 00D fit the Q^2 dependence ($200 < Q^2 < 22500 \text{ GeV}^2$) of the charged-current differential cross sections with a propagator mass fit. The last error is due to the uncertainty on the probability density functions.
- ¹⁴ ALITTI 92B result has two contributions to the systematic error (± 0.83); one (± 0.81) cancels in m_W/m_Z and one (± 0.17) is noncancelling. These were added in quadrature. We choose the ALITTI 92B value without using the LEP m_Z value, because we perform our own combined fit.
- ¹⁵ There are two contributions to the systematic error (± 0.84): one (± 0.81) which cancels in m_W/m_Z and one (± 0.21) which is non-cancelling. These were added in quadrature.
- ¹⁶ ABE 89I systematic error dominated by the uncertainty in the absolute energy scale.
- ¹⁷ ALBAJAR 89 result is from a total sample of 299 $W \rightarrow e\nu$ events.
- ¹⁸ ALBAJAR 89 result is from a total sample of 67 $W \rightarrow \mu\nu$ events.
- ¹⁹ ALBAJAR 89 result is from $W \rightarrow \tau\nu$ events.

W/Z MASS RATIO

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.8819 ± 0.0012 OUR AVERAGE				
0.8821 ± 0.0011 ± 0.0008	28323	¹ ABBOTT	98N D0	$E_{\text{cm}}^{p\bar{p}} = 1.8 \text{ TeV}$
0.88114 ± 0.00154 ± 0.00252	5982	² ABBOTT	98P D0	$E_{\text{cm}}^{p\bar{p}} = 1.8 \text{ TeV}$
0.8813 ± 0.0036 ± 0.0019	156	³ ALITTI	92B UA2	$E_{\text{cm}}^{p\bar{p}} = 630 \text{ GeV}$

¹ ABBOTT 98N obtain this from a study of 28323 $W \rightarrow e\nu_e$ and 3294 $Z \rightarrow e^+e^-$ decays. Of this latter sample, 2179 events are used to calibrate the electron energy scale.

² ABBOTT 98P obtain this from a study of 5982 $W \rightarrow e\nu_e$ events. The systematic error includes an uncertainty of ± 0.00175 due to the electron energy scale.

³ Scale error cancels in this ratio.

$m_Z - m_W$

VALUE (GeV)	DOCUMENT ID	TECN	COMMENT
10.4 ± 1.4 ± 0.8	ALBAJAR 89	UA1	$E_{\text{cm}}^{p\bar{p}} = 546,630 \text{ GeV}$
• • • We do not use the following data for averages, fits, limits, etc. • • •			
11.3 ± 1.3 ± 0.9	ANSARI 87	UA2	$E_{\text{cm}}^{p\bar{p}} = 546,630 \text{ GeV}$

$m_{W^+} - m_{W^-}$

Test of *CPT* invariance.

VALUE (GeV)	EVTS	DOCUMENT ID	TECN	COMMENT
-0.19 ± 0.58	1722	ABE	90G CDF	$E_{\text{cm}}^{p\bar{p}} = 1.8 \text{ TeV}$

W WIDTH

The W width listed here corresponds to the width parameter in a Breit-Wigner distribution with mass-dependent width. To obtain the world average, common systematic uncertainties between experiments are properly taken into account. The LEP-2 average W width based on published results is 2.195 ± 0.083 GeV [SCHAEL 13A]. The combined Tevatron data yields an average W width of 2.046 ± 0.049 GeV [FERMILAB-TM-2460-E].

OUR FIT uses these average LEP and Tevatron width values and combines them assuming no correlations.

<u>VALUE (GeV)</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
2.085±0.042 OUR FIT				
2.028 ± 0.072	5272	¹ ABAZOV	09AK D0	$E_{\text{cm}}^{p\bar{p}} = 1.96$ GeV
$2.032 \pm 0.045 \pm 0.057$	6055	² AALTONEN	08B CDF	$E_{\text{cm}}^{p\bar{p}} = 1.96$ TeV
$2.404 \pm 0.140 \pm 0.101$	10.3k	³ ABDALLAH	08A DLPH	$E_{\text{cm}}^{ee} = 183\text{--}209$ GeV
$1.996 \pm 0.096 \pm 0.102$	10729	⁴ ABBIENDI	06 OPAL	$E_{\text{cm}}^{ee} = 170\text{--}209$ GeV
$2.18 \pm 0.11 \pm 0.09$	9795	⁵ ACHARD	06 L3	$E_{\text{cm}}^{ee} = 172\text{--}209$ GeV
$2.14 \pm 0.09 \pm 0.06$	8717	⁶ SCHAEL	06 ALEP	$E_{\text{cm}}^{ee} = 183\text{--}209$ GeV
$2.23^{+0.15}_{-0.14} \pm 0.10$	294	⁷ ABAZOV	02E D0	Direct meas.
$2.05 \pm 0.10 \pm 0.08$	662	⁸ AFFOLDER	00M CDF	Direct meas.
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
2.152 ± 0.066	79176	⁹ ABBOTT	00B D0	Extracted value
$2.064 \pm 0.060 \pm 0.059$		¹⁰ ABE	95W CDF	Extracted value
$2.10^{+0.14}_{-0.13} \pm 0.09$	3559	¹¹ ALITTI	92 UA2	Extracted value
$2.18^{+0.26}_{-0.24} \pm 0.04$		¹² ALBAJAR	91 UA1	Extracted value

¹ ABAZOV 09AK obtain this result fitting the high-end tail (100–200 GeV) of the transverse mass spectrum in $W \rightarrow e\nu$ decays.

² AALTONEN 08B obtain this result fitting the high-end tail (90–200 GeV) of the transverse mass spectrum in semileptonic $W \rightarrow e\nu_e$ and $W \rightarrow \mu\nu_\mu$ decays.

³ ABDALLAH 08A use direct reconstruction of the kinematics of $W^+W^- \rightarrow q\bar{q}\ell\nu$ and $W^+W^- \rightarrow q\bar{q}q\bar{q}$ events. The systematic error includes ± 0.065 GeV due to final state interactions.

⁴ ABBIENDI 06 use direct reconstruction of the kinematics of $W^+W^- \rightarrow q\bar{q}\ell\nu_\ell$ and $W^+W^- \rightarrow q\bar{q}q\bar{q}$ events. The systematic error includes ± 0.003 GeV due to the uncertainty on the LEP beam energy.

⁵ ACHARD 06 use direct reconstruction of the kinematics of $W^+W^- \rightarrow q\bar{q}\ell\nu_\ell$ and $W^+W^- \rightarrow q\bar{q}q\bar{q}$ events in the C.M. energy range 189–209 GeV. The result quoted here is obtained combining this value of the width with the result obtained from a direct W mass reconstruction at 172 and 183 GeV (ACCIARRI 99).

⁶ SCHAEL 06 use direct reconstruction of the kinematics of $W^+W^- \rightarrow q\bar{q}\ell\nu_\ell$ and $W^+W^- \rightarrow q\bar{q}q\bar{q}$ events. The systematic error includes ± 0.05 GeV due to possible effects of final state interactions in the $q\bar{q}q\bar{q}$ channel and ± 0.01 GeV due to the uncertainty on the LEP beam energy.

⁷ ABAZOV 02E obtain this result fitting the high-end tail (90–200 GeV) of the transverse-mass spectrum in semileptonic $W \rightarrow e\nu_e$ decays.

- ⁸ AFFOLDER 00M fit the high transverse mass (100–200 GeV) $W \rightarrow e\nu_e$ and $W \rightarrow \mu\nu_\mu$ events to obtain $\Gamma(W) = 2.04 \pm 0.11(\text{stat}) \pm 0.09(\text{syst})$ GeV. This is combined with the earlier CDF measurement (ABE 95C) to obtain the quoted result.
- ⁹ ABBOTT 00B measure $R = 10.43 \pm 0.27$ for the $W \rightarrow e\nu_e$ decay channel. They use the SM theoretical predictions for $\sigma(W)/\sigma(Z)$ and $\Gamma(W \rightarrow e\nu_e)$ and the world average for $B(Z \rightarrow ee)$. The value quoted here is obtained combining this result (2.169 ± 0.070 GeV) with that of ABBOTT 99H.
- ¹⁰ ABE 95W measured $R = 10.90 \pm 0.32 \pm 0.29$. They use $m_W = 80.23 \pm 0.18$ GeV, $\sigma(W)/\sigma(Z) = 3.35 \pm 0.03$, $\Gamma(W \rightarrow e\nu) = 225.9 \pm 0.9$ MeV, $\Gamma(Z \rightarrow e^+e^-) = 83.98 \pm 0.18$ MeV, and $\Gamma(Z) = 2.4969 \pm 0.0038$ GeV.
- ¹¹ ALITTI 92 measured $R = 10.4^{+0.7}_{-0.6} \pm 0.3$. The values of $\sigma(Z)$ and $\sigma(W)$ come from $O(\alpha_s^2)$ calculations using $m_W = 80.14 \pm 0.27$ GeV, and $m_Z = 91.175 \pm 0.021$ GeV along with the corresponding value of $\sin^2\theta_W = 0.2274$. They use $\sigma(W)/\sigma(Z) = 3.26 \pm 0.07 \pm 0.05$ and $\Gamma(Z) = 2.487 \pm 0.010$ GeV.
- ¹² ALBAJAR 91 measured $R = 9.5^{+1.1}_{-1.0}$ (stat. + syst.). $\sigma(W)/\sigma(Z)$ is calculated in QCD at the parton level using $m_W = 80.18 \pm 0.28$ GeV and $m_Z = 91.172 \pm 0.031$ GeV along with $\sin^2\theta_W = 0.2322 \pm 0.0014$. They use $\sigma(W)/\sigma(Z) = 3.23 \pm 0.05$ and $\Gamma(Z) = 2.498 \pm 0.020$ GeV. This measurement is obtained combining both the electron and muon channels.

W⁺ DECAY MODES

W^- modes are charge conjugates of the modes below.

Mode	Fraction (Γ_i/Γ)	Confidence level
Γ_1 $\ell^+\nu$	[a] $(10.86 \pm 0.09) \%$	
Γ_2 $e^+\nu$	$(10.71 \pm 0.16) \%$	
Γ_3 $\mu^+\nu$	$(10.63 \pm 0.15) \%$	
Γ_4 $\tau^+\nu$	$(11.38 \pm 0.21) \%$	
Γ_5 hadrons	$(67.41 \pm 0.27) \%$	
Γ_6 $\pi^+\gamma$	$< 7 \times 10^{-5}$	95%
Γ_7 $D_s^+\gamma$	$< 1.3 \times 10^{-3}$	95%
Γ_8 cX	$(33.3 \pm 2.6) \%$	
Γ_9 $c\bar{s}$	$(31^{+13}_{-11}) \%$	
Γ_{10} invisible	[b] $(1.4 \pm 2.9) \%$	

[a] ℓ indicates each type of lepton (e , μ , and τ), not sum over them.

[b] This represents the width for the decay of the W boson into a charged particle with momentum below detectability, $p < 200$ MeV.

W PARTIAL WIDTHS

$\Gamma(\text{invisible})$

 Γ_{10}

This represents the width for the decay of the W boson into a charged particle with momentum below detectability, $p < 200$ MeV.

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
$30^{+52}_{-48} \pm 33$	¹ BARATE	99I ALEP	$E_{\text{cm}}^{ee} = 161+172+183$ GeV

• • • We do not use the following data for averages, fits, limits, etc. • • •

	² BARATE	99L ALEP	$E_{\text{cm}}^{ee} = 161+172+183$ GeV
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¹ BARATE 99I measure this quantity using the dependence of the total cross section σ_{WW} upon a change in the total width. The fit is performed to the WW measured cross sections at 161, 172, and 183 GeV. This partial width is < 139 MeV at 95%CL.

² BARATE 99L use W -pair production to search for effectively invisible W decays, tagging with the decay of the other W boson to Standard Model particles. The partial width for effectively invisible decay is < 27 MeV at 95%CL.

W BRANCHING RATIOS

Overall fits are performed to determine the branching ratios of the W boson. Averages on $W \rightarrow e\nu$, $W \rightarrow \mu\nu$, and $W \rightarrow \tau\nu$, and their correlations are obtained by combining results from the four LEP experiments properly taking into account the common systematic uncertainties and their correlations [SCHAEEL 13A]. A first fit determines the three individual leptonic branching ratios $B(W \rightarrow e\nu)$, $B(W \rightarrow \mu\nu)$, and $B(W \rightarrow \tau\nu)$. This fit has a $\chi^2 = 6.3$ for 9 degrees of freedom. The correlation coefficients between the branching fractions are 0.14 ($e-\mu$), -0.20 ($e-\tau$), -0.12 ($\mu-\tau$). A second fit assumes lepton universality and determines the leptonic branching ratio $\text{br}W \rightarrow \ell\nu$ and the hadronic branching ratio is derived as $B(W \rightarrow \text{hadrons}) = 1-3 \text{br}W \rightarrow \ell$. This fit has a $\chi^2 = 15.4$ for 11 degrees of freedom.

$\Gamma(\ell^+ \nu)/\Gamma_{\text{total}}$

 Γ_1/Γ

ℓ indicates average over e , μ , and τ modes, not sum over modes.

VALUE (units 10^{-2})	EVTS	DOCUMENT ID	TECN	COMMENT
10.86 ± 0.09 OUR FIT				
$10.86 \pm 0.12 \pm 0.08$	16438	ABBIENDI	07A OPAL	$E_{\text{cm}}^{ee} = 161-209$ GeV
$10.85 \pm 0.14 \pm 0.08$	13600	ABDALLAH	04G DLPH	$E_{\text{cm}}^{ee} = 161-209$ GeV
$10.83 \pm 0.14 \pm 0.10$	11246	ACHARD	04J L3	$E_{\text{cm}}^{ee} = 161-209$ GeV
$10.96 \pm 0.12 \pm 0.05$	16116	SCHAEEL	04A ALEP	$E_{\text{cm}}^{ee} = 183-209$ GeV

• • • We do not use the following data for averages, fits, limits, etc. • • •

11.02 ± 0.52	11858	¹ ABBOTT	99H D0	$E_{\text{cm}}^{p\bar{p}} = 1.8$ TeV
10.4 ± 0.8	3642	² ABE	92I CDF	$E_{\text{cm}}^{p\bar{p}} = 1.8$ TeV

¹ ABBOTT 99H measure $R \equiv [\sigma_W B(W \rightarrow \ell\nu_\ell)]/[\sigma_Z B(Z \rightarrow \ell\ell)] = 10.90 \pm 0.52$ combining electron and muon channels. They use $M_W = 80.39 \pm 0.06$ GeV and the SM theoretical predictions for $\sigma(W)/\sigma(Z)$ and $B(Z \rightarrow \ell\ell)$.

² $1216 \pm 38^{+27}_{-31}$ $W \rightarrow \mu\nu$ events from ABE 92I and $2426 W \rightarrow e\nu$ events of ABE 91C. ABE 92I give the inverse quantity as 9.6 ± 0.7 and we have inverted.

$\Gamma(e^+ \nu) / \Gamma_{\text{total}}$ Γ_2 / Γ

<u>VALUE (units 10^{-2})</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
10.71 ± 0.16 OUR FIT				
10.71 ± 0.25 ± 0.11	2374	ABBIENDI	07A OPAL	$E_{\text{cm}}^{ee} = 161\text{--}209$ GeV
10.55 ± 0.31 ± 0.14	1804	ABDALLAH	04G DLPH	$E_{\text{cm}}^{ee} = 161\text{--}209$ GeV
10.78 ± 0.29 ± 0.13	1576	ACHARD	04J L3	$E_{\text{cm}}^{ee} = 161\text{--}209$ GeV
10.78 ± 0.27 ± 0.10	2142	SCHAEL	04A ALEP	$E_{\text{cm}}^{ee} = 183\text{--}209$ GeV

• • • We do not use the following data for averages, fits, limits, etc. • • •

10.61 ± 0.28 ¹ ABAZOV 04D TEVA $E_{\text{cm}}^{p\bar{p}} = 1.8$ TeV

¹ ABAZOV 04D take into account all correlations to properly combine the CDF (ABE 95W) and $D\bar{D}$ (ABBOTT 00B) measurements of the ratio R in the electron channel. The ratio R is defined as $[\sigma_W \cdot B(W \rightarrow e\nu_e)] / [\sigma_Z \cdot B(Z \rightarrow ee)]$. The combination gives $R^{\text{TeVatron}} = 10.59 \pm 0.23$. σ_W / σ_Z is calculated at next-to-next-to-leading order (3.360 ± 0.051). The branching fraction $B(Z \rightarrow ee)$ is taken from this Review as (3.363 ± 0.004)%.

 $\Gamma(\mu^+ \nu) / \Gamma_{\text{total}}$ Γ_3 / Γ

<u>VALUE (units 10^{-2})</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
10.63 ± 0.15 OUR FIT				
10.78 ± 0.24 ± 0.10	2397	ABBIENDI	07A OPAL	$E_{\text{cm}}^{ee} = 161\text{--}209$ GeV
10.65 ± 0.26 ± 0.08	1998	ABDALLAH	04G DLPH	$E_{\text{cm}}^{ee} = 161\text{--}209$ GeV
10.03 ± 0.29 ± 0.12	1423	ACHARD	04J L3	$E_{\text{cm}}^{ee} = 161\text{--}209$ GeV
10.87 ± 0.25 ± 0.08	2216	SCHAEL	04A ALEP	$E_{\text{cm}}^{ee} = 183\text{--}209$ GeV

 $\Gamma(\tau^+ \nu) / \Gamma_{\text{total}}$ Γ_4 / Γ

<u>VALUE (units 10^{-2})</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
11.38 ± 0.21 OUR FIT				
11.14 ± 0.31 ± 0.17	2177	ABBIENDI	07A OPAL	$E_{\text{cm}}^{ee} = 161\text{--}209$ GeV
11.46 ± 0.39 ± 0.19	2034	ABDALLAH	04G DLPH	$E_{\text{cm}}^{ee} = 161\text{--}209$ GeV
11.89 ± 0.40 ± 0.20	1375	ACHARD	04J L3	$E_{\text{cm}}^{ee} = 161\text{--}209$ GeV
11.25 ± 0.32 ± 0.20	2070	SCHAEL	04A ALEP	$E_{\text{cm}}^{ee} = 183\text{--}209$ GeV

 $\Gamma(\text{hadrons}) / \Gamma_{\text{total}}$ Γ_5 / Γ

OUR FIT value is obtained by a fit to the lepton branching ratio data assuming lepton universality.

<u>VALUE (units 10^{-2})</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
67.41 ± 0.27 OUR FIT				
67.41 ± 0.37 ± 0.23	16438	ABBIENDI	07A OPAL	$E_{\text{cm}}^{ee} = 161\text{--}209$ GeV
67.45 ± 0.41 ± 0.24	13600	ABDALLAH	04G DLPH	$E_{\text{cm}}^{ee} = 161\text{--}209$ GeV
67.50 ± 0.42 ± 0.30	11246	ACHARD	04J L3	$E_{\text{cm}}^{ee} = 161\text{--}209$ GeV
67.13 ± 0.37 ± 0.15	16116	SCHAEL	04A ALEP	$E_{\text{cm}}^{ee} = 183\text{--}209$ GeV

$\Gamma(\mu^+\nu)/\Gamma(e^+\nu)$ Γ_3/Γ_2

<u>VALUE</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
0.993±0.019 OUR FIT				
0.89 ±0.10	13k	¹ ABACHI	95D D0	$E_{cm}^{p\bar{p}} = 1.8$ TeV
1.02 ±0.08	1216	² ABE	92I CDF	$E_{cm}^{p\bar{p}} = 1.8$ TeV
1.00 ±0.14 ±0.08	67	ALBAJAR	89 UA1	$E_{cm}^{p\bar{p}} = 546,630$ GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1.24 ^{+0.6} _{-0.4}	14	ARNISON	84D UA1	Repl. by ALBAJAR 89

¹ ABACHI 95D obtain this result from the measured $\sigma_W B(W \rightarrow \mu\nu) = 2.09 \pm 0.23 \pm 0.11$ nb and $\sigma_W B(W \rightarrow e\nu) = 2.36 \pm 0.07 \pm 0.13$ nb in which the first error is the combined statistical and systematic uncertainty, the second reflects the uncertainty in the luminosity.

² ABE 92I obtain $\sigma_W B(W \rightarrow \mu\nu) = 2.21 \pm 0.07 \pm 0.21$ and combine with ABE 91C $\sigma_W B(W \rightarrow e\nu)$ to give a ratio of the couplings from which we derive this measurement.

 $\Gamma(\tau^+\nu)/\Gamma(e^+\nu)$ Γ_4/Γ_2

<u>VALUE</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
1.063±0.027 OUR FIT				
0.961±0.061	980	¹ ABBOTT	00D D0	$E_{cm}^{p\bar{p}} = 1.8$ TeV
0.94 ±0.14	179	² ABE	92E CDF	$E_{cm}^{p\bar{p}} = 1.8$ TeV
1.04 ±0.08 ±0.08	754	³ ALITTI	92F UA2	$E_{cm}^{p\bar{p}} = 630$ GeV
1.02 ±0.20 ±0.12	32	ALBAJAR	89 UA1	$E_{cm}^{p\bar{p}} = 546,630$ GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.995±0.112±0.083	198	ALITTI	91C UA2	Repl. by ALITTI 92F
1.02 ±0.20 ±0.10	32	ALBAJAR	87 UA1	Repl. by ALBAJAR 89

¹ ABBOTT 00D measure $\sigma_W \times B(W \rightarrow \tau\nu_\tau) = 2.22 \pm 0.09 \pm 0.10 \pm 0.10$ nb. Using the ABBOTT 00B result $\sigma_W \times B(W \rightarrow e\nu_e) = 2.31 \pm 0.01 \pm 0.05 \pm 0.10$ nb, they quote the ratio of the couplings from which we derive this measurement.

² ABE 92E use two procedures for selecting $W \rightarrow \tau\nu_\tau$ events. The missing E_T trigger leads to $132 \pm 14 \pm 8$ events and the τ trigger to $47 \pm 9 \pm 4$ events. Proper statistical and systematic correlations are taken into account to arrive at $\sigma B(W \rightarrow \tau\nu) = 2.05 \pm 0.27$ nb. Combined with ABE 91C result on $\sigma B(W \rightarrow e\nu)$, ABE 92E quote a ratio of the couplings from which we derive this measurement.

³ This measurement is derived by us from the ratio of the couplings of ALITTI 92F.

 $\Gamma(\pi^+\gamma)/\Gamma(e^+\nu)$ Γ_6/Γ_2

<u>VALUE</u>	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
< 7 × 10⁻⁴	95	ABE	98H CDF	$E_{cm}^{p\bar{p}} = 1.8$ TeV
< 4.9 × 10 ⁻³	95	¹ ALITTI	92D UA2	$E_{cm}^{p\bar{p}} = 630$ GeV
< 58 × 10 ⁻³	95	² ALBAJAR	90 UA1	$E_{cm}^{p\bar{p}} = 546, 630$ GeV

¹ ALITTI 92D limit is 3.8×10^{-3} at 90%CL.

² ALBAJAR 90 obtain < 0.048 at 90%CL.

 $\Gamma(D_s^+\gamma)/\Gamma(e^+\nu)$ Γ_7/Γ_2

<u>VALUE</u>	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
< 1.2 × 10⁻²	95	ABE	98P CDF	$E_{cm}^{p\bar{p}} = 1.8$ TeV

$\Gamma(cX)/\Gamma(\text{hadrons})$				Γ_8/Γ_5	
VALUE	EVTS	DOCUMENT ID	TECN	COMMENT	
0.49 ± 0.04	OUR AVERAGE				
$0.481 \pm 0.042 \pm 0.032$	3005	¹ ABBIENDI	00V OPAL	$E_{\text{cm}}^{ee} = 183 + 189 \text{ GeV}$	
$0.51 \pm 0.05 \pm 0.03$	746	² BARATE	99M ALEP	$E_{\text{cm}}^{ee} = 172 + 183 \text{ GeV}$	

¹ ABBIENDI 00V tag $W \rightarrow cX$ decays using measured jet properties, lifetime information, and leptons produced in charm decays. From this result, and using the additional measurements of $\Gamma(W)$ and $B(W \rightarrow \text{hadrons})$, $|V_{cs}|$ is determined to be $0.969 \pm 0.045 \pm 0.036$.

² BARATE 99M tag c jets using a neural network algorithm. From this measurement $|V_{cs}|$ is determined to be $1.00 \pm 0.11 \pm 0.07$.

$R_{cs} = \Gamma(c\bar{s})/\Gamma(\text{hadrons})$				Γ_9/Γ_5	
VALUE		DOCUMENT ID	TECN	COMMENT	
$0.46^{+0.18}_{-0.14} \pm 0.07$		¹ ABREU	98N DLPH	$E_{\text{cm}}^{ee} = 161+172 \text{ GeV}$	

¹ ABREU 98N tag c and s jets by identifying a charged kaon as the highest momentum particle in a hadronic jet. They also use a lifetime tag to independently identify a c jet, based on the impact parameter distribution of charged particles in a jet. From this measurement $|V_{cs}|$ is determined to be $0.94^{+0.32}_{-0.26} \pm 0.13$.

AVERAGE PARTICLE MULTIPLICITIES IN HADRONIC W DECAY

Summed over particle and antiparticle, when appropriate.

$\langle N_{\pi^\pm} \rangle$				
VALUE		DOCUMENT ID	TECN	COMMENT
15.70 ± 0.35		¹ ABREU,P	00F DLPH	$E_{\text{cm}}^{ee} = 189 \text{ GeV}$

¹ ABREU,P 00F measure $\langle N_{\pi^\pm} \rangle = 31.65 \pm 0.48 \pm 0.76$ and $15.51 \pm 0.38 \pm 0.40$ in the fully hadronic and semileptonic final states respectively. The value quoted is a weighted average without assuming any correlations.

$\langle N_{K^\pm} \rangle$				
VALUE		DOCUMENT ID	TECN	COMMENT
2.20 ± 0.19		¹ ABREU,P	00F DLPH	$E_{\text{cm}}^{ee} = 189 \text{ GeV}$

¹ ABREU,P 00F measure $\langle N_{K^\pm} \rangle = 4.38 \pm 0.42 \pm 0.12$ and $2.23 \pm 0.32 \pm 0.17$ in the fully hadronic and semileptonic final states respectively. The value quoted is a weighted average without assuming any correlations.

$\langle N_p \rangle$				
VALUE		DOCUMENT ID	TECN	COMMENT
0.92 ± 0.14		¹ ABREU,P	00F DLPH	$E_{\text{cm}}^{ee} = 189 \text{ GeV}$

¹ ABREU,P 00F measure $\langle N_p \rangle = 1.82 \pm 0.29 \pm 0.16$ and $0.94 \pm 0.23 \pm 0.06$ in the fully hadronic and semileptonic final states respectively. The value quoted is a weighted average without assuming any correlations.

$\langle N_{\text{charged}} \rangle$

VALUE	DOCUMENT ID	TECN	COMMENT
19.39 ± 0.08 OUR AVERAGE			
19.38 ± 0.05 ± 0.08	¹ ABBIENDI 06A	OPAL	$E_{\text{cm}}^{ee} = 189\text{--}209$ GeV
19.44 ± 0.17	² ABREU,P 00F	DLPH	$E_{\text{cm}}^{ee} = 183\text{--}189$ GeV
19.3 ± 0.3 ± 0.3	³ ABBIENDI 99N	OPAL	$E_{\text{cm}}^{ee} = 183$ GeV
19.23 ± 0.74	⁴ ABREU 98C	DLPH	$E_{\text{cm}}^{ee} = 172$ GeV

¹ ABBIENDI 06A measure $\langle N_{\text{charged}} \rangle = 38.74 \pm 0.12 \pm 0.26$ when both W bosons decay hadronically and $\langle N_{\text{charged}} \rangle = 19.39 \pm 0.11 \pm 0.09$ when one W boson decays semileptonically. The value quoted here is obtained under the assumption that there is no color reconnection between W bosons; the value is a weighted average taking into account correlations in the systematic uncertainties.

² ABREU,P 00F measure $\langle N_{\text{charged}} \rangle = 39.12 \pm 0.33 \pm 0.36$ and $38.11 \pm 0.57 \pm 0.44$ in the fully hadronic final states at 189 and 183 GeV respectively, and $\langle N_{\text{charged}} \rangle = 19.49 \pm 0.31 \pm 0.27$ and $19.78 \pm 0.49 \pm 0.43$ in the semileptonic final states. The value quoted is a weighted average without assuming any correlations.

³ ABBIENDI 99N use the final states $W^+ W^- \rightarrow q\bar{q}\ell\bar{\nu}_\ell$ to derive this value.

⁴ ABREU 98C combine results from both the fully hadronic as well semileptonic $W W$ final states after demonstrating that the W decay charged multiplicity is independent of the topology within errors.

TRIPLE GAUGE COUPLINGS (TGC'S)

A REVIEW GOES HERE – Check our WWW List of Reviews

g_1^Z

OUR FIT below is taken from [SCHAEL 13A].

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.984^{+0.018}_{-0.020} OUR FIT				
0.975 ^{+0.033} _{-0.030}	7872	¹ ABDALLAH 10	DLPH	$E_{\text{cm}}^{ee} = 189\text{--}209$ GeV
1.001 ± 0.027 ± 0.013	9310	² SCHAEL 05A	ALEP	$E_{\text{cm}}^{ee} = 183\text{--}209$ GeV
0.987 ^{+0.034} _{-0.033}	9800	³ ABBIENDI 04D	OPAL	$E_{\text{cm}}^{ee} = 183\text{--}209$ GeV
0.966 ^{+0.034} _{-0.032} ± 0.015	8325	⁴ ACHARD 04D	L3	$E_{\text{cm}}^{ee} = 161\text{--}209$ GeV

• • • We do not use the following data for averages, fits, limits, etc. • • •

	⁵ AAD 13AL	ATLS	$E_{\text{cm}}^{pp} = 7$ TeV
	⁶ CHATRCHYAN 13BF	CMS	$E_{\text{cm}}^{pp} = 7$ TeV
	⁷ AAD 12CD	ATLS	$E_{\text{cm}}^{pp} = 7$ TeV
	⁸ AALTONEN 12AC	CDF	$E_{\text{cm}}^{p\bar{p}} = 1.96$ TeV
	⁹ ABAZOV 12AG	D0	$E_{\text{cm}}^{p\bar{p}} = 1.96$ TeV
34	¹⁰ ABAZOV 11	D0	$E_{\text{cm}}^{p\bar{p}} = 1.96$ TeV
334	¹¹ AALTONEN 10K	CDF	$E_{\text{cm}}^{p\bar{p}} = 1.96$ TeV

1.04 ±0.09		12	ABAZOV	09AD D0	$E_{\text{cm}}^{p\bar{p}} = 1.96 \text{ TeV}$	
		13	ABAZOV	09AJ D0	$E_{\text{cm}}^{p\bar{p}} = 1.96 \text{ TeV}$	
1.07 $\begin{smallmatrix} +0.08 \\ -0.12 \end{smallmatrix}$	1880	14	ABDALLAH	08C DLPH	Superseded by ABDAL- LAH 10	
		13	15	ABAZOV	07Z D0	$E_{\text{cm}}^{p\bar{p}} = 1.96 \text{ TeV}$
		2.3	16	ABAZOV	05S D0	$E_{\text{cm}}^{p\bar{p}} = 1.96 \text{ TeV}$
0.98 ±0.07 ±0.01	2114		17	ABREU	01I DLPH	$E_{\text{cm}}^{ee} = 183+189 \text{ GeV}$
	331		18	ABBOTT	99I D0	$E_{\text{cm}}^{p\bar{p}} = 1.8 \text{ TeV}$

¹ ABDALLAH 10 use data on the final states $e^+e^- \rightarrow jj\ell\nu, jjjj, jjX, \ell X$, at center-of-mass energies between 189–209 GeV at LEP2, where $j = \text{jet}$, $\ell = \text{lepton}$, and X represents missing momentum. The fit is carried out keeping all other parameters fixed at their SM values.

² SCHAEL 05A study single-photon, single- W , and WW -pair production from 183 to 209 GeV. The result quoted here is derived from the WW -pair production sample. Each parameter is determined from a single-parameter fit in which the other parameters assume their Standard Model values.

³ ABBIENDI 04D combine results from W^+W^- in all decay channels. Only CP -conserving couplings are considered and each parameter is determined from a single-parameter fit in which the other parameters assume their Standard Model values. The 95% confidence interval is $0.923 < g_1^Z < 1.054$.

⁴ ACHARD 04D study WW -pair production, single- W production and single-photon production with missing energy from 189 to 209 GeV. The result quoted here is obtained from the WW -pair production sample including data from 161 to 183 GeV, ACCIARRI 99Q. Each parameter is determined from a single-parameter fit in which the other parameters assume their Standard Model values.

⁵ AAD 13AL study WW production in pp collisions and select 1325 WW candidates in decay modes with electrons or muons with an expected background of 369 ± 61 events. Assuming the LEP formulation and setting the form-factor $\Lambda = \text{infinity}$, a fit to the transverse momentum distribution of the leading charged lepton, leads to a 95% C.L. range of $0.961 < g_1^Z < 1.052$. Supersedes AAD 12AC.

⁶ CHATRCHYAN 13BF determine the W^+W^- production cross section using unlike sign di-lepton (e or μ) events with high p_T . The leptons have $p_T > 20 \text{ GeV}/c$ and are isolated. 1134 candidate events are observed with an expected SM background of 247 ± 34 . The p_T distribution of the leading lepton is fitted to obtain 95% C.L. limits of $0.905 \leq g_1^Z \leq 1.095$.

⁷ AAD 12CD study WZ production in pp collisions and select 317 WZ candidates in three $\ell\nu$ decay modes with an expected background of 68.0 ± 10.0 events. The resulting 95% C.L. range is: $0.943 < g_1^Z < 1.093$. Supersedes AAD 12V.

⁸ AALTONEN 12AC study WZ production in $p\bar{p}$ collisions and select 63 WZ candidates in three $\ell\nu$ decay modes with an expected background of 7.9 ± 1.0 events. Based on the cross section and shape of the Z transverse momentum spectrum, the following 95% C.L. range is reported: $0.92 < g_1^Z < 1.20$ for a form factor of $\Lambda = 2 \text{ TeV}$.

⁹ ABAZOV 12AG combine new results with already published results on $W\gamma$, WW and WZ production in order to determine the couplings with increased precision, superseding ABAZOV 08R, ABAZOV 11AC, ABAZOV 09AJ, ABAZOV 09AD. The 68% C.L. result for a formfactor cutoff of $\Lambda = 2 \text{ TeV}$ is $g_1^Z = 1.022^{+0.032}_{-0.030}$.

¹⁰ ABAZOV 11 study the $p\bar{p} \rightarrow 3\ell\nu$ process arising in WZ production. They observe 34 WZ candidates with an estimated background of 6 events. An analysis of the p_T spectrum of the Z boson leads to a 95% C.L. limit of $0.944 < g_1^Z < 1.154$, for a form factor $\Lambda = 2 \text{ TeV}$.

- 11 AALTONEN 10K study $p\bar{p} \rightarrow W^+W^-$ with $W \rightarrow e/\mu\nu$. The p_T of the leading (second) lepton is required to be > 20 (10) GeV. The final number of events selected is 654 of which 320 ± 47 are estimated to be background. The 95% C.L. interval is $0.76 < g_1^Z < 1.34$ for $\Lambda = 1.5$ TeV and $0.78 < g_1^Z < 1.30$ for $\Lambda = 2$ TeV.
- 12 ABAZOV 09AD study the $p\bar{p} \rightarrow \ell\nu$ 2jet process arising in WW and WZ production. They select 12,473 (14,392) events in the electron (muon) channel with an expected di-boson signal of 436 (527) events. The results on the anomalous couplings are derived from an analysis of the p_T spectrum of the 2-jet system and quoted at 68% C.L. and for a form factor of 2 TeV. This measurement is not used for obtaining the mean as it is for a specific form factor. The 95% confidence interval is $0.88 < g_1^Z < 1.20$.
- 13 ABAZOV 09AJ study the $p\bar{p} \rightarrow 2\ell 2\nu$ process arising in WW production. They select 100 events with an expected WW signal of 65 events. An analysis of the p_T spectrum of the two charged leptons leads to 95% C.L. limits of $0.86 < g_1^Z < 1.3$, for a form factor $\Lambda = 2$ TeV.
- 14 ABDALLAH 08C determine this triple gauge coupling from the measurement of the spin density matrix elements in $e^+e^- \rightarrow W^+W^- \rightarrow (qq)(\ell\nu)$, where $\ell = e$ or μ . Values of all other couplings are fixed to their standard model values.
- 15 ABAZOV 07Z set limits on anomalous TGCs using the measured cross section and $p_T(Z)$ distribution in WZ production with both the W and the Z decaying leptonically into electrons and muons. Setting the other couplings to their standard model values, the 95% C.L. limit for a form factor scale $\Lambda = 2$ TeV is $0.86 < g_1^Z < 1.35$.
- 16 ABAZOV 05S study $p\bar{p} \rightarrow WZ$ production with a subsequent trilepton decay to $\ell\nu\ell'\bar{\ell}'$ (ℓ and $\ell' = e$ or μ). Three events (estimated background 0.71 ± 0.08 events) with WZ decay characteristics are observed from which they derive limits on the anomalous WWZ couplings. The 95% CL limit for a form factor scale $\Lambda = 1.5$ TeV is $0.51 < g_1^Z < 1.66$, fixing λ_Z and κ_Z to their Standard Model values.
- 17 ABREU 01I combine results from e^+e^- interactions at 189 GeV leading to W^+W^- and $W e \nu_e$ final states with results from ABREU 99L at 183 GeV. The 95% confidence interval is $0.84 < g_1^Z < 1.13$.
- 18 ABBOTT 99I perform a simultaneous fit to the $W\gamma$, $WW \rightarrow$ dilepton, $WW/WZ \rightarrow e\nu jj$, $WW/WZ \rightarrow \mu\nu jj$, and $WZ \rightarrow$ trilepton data samples. For $\Lambda = 2.0$ TeV, the 95%CL limits are $0.63 < g_1^Z < 1.57$, fixing λ_Z and κ_Z to their Standard Model values, and assuming Standard Model values for the $WW\gamma$ couplings.

κ_γ

OUR FIT below is taken from [SCHAEL 13A].

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.982 ± 0.042 OUR FIT				
$1.024^{+0.077}_{-0.081}$	7872	1 ABDALLAH	10 DLPH	$E_{cm}^{ee} = 189-209$ GeV
$0.971 \pm 0.055 \pm 0.030$	10689	2 SCHAEL	05A ALEP	$E_{cm}^{ee} = 183-209$ GeV
$0.88^{+0.09}_{-0.08}$	9800	3 ABBIENDI	04D OPAL	$E_{cm}^{ee} = 183-209$ GeV
$1.013^{+0.067}_{-0.064} \pm 0.026$	10575	4 ACHARD	04D L3	$E_{cm}^{ee} = 161-209$ GeV

• • • We do not use the following data for averages, fits, limits, etc. • • •

5 AAD	13AN ATLS	$E_{cm}^{pp} = 7$ TeV
6 CHATRCHYAN 13BF	CMS	$E_{cm}^{pp} = 7$ TeV

		7	ABAZOV	12AG	D0	$E_{\text{cm}}^{p\bar{p}} = 1.96$ TeV		
		8	ABAZOV	11AC	D0	$E_{\text{cm}}^{p\bar{p}} = 1.96$ TeV		
		9	CHATRCHYAN	11M	CMS	$E_{\text{cm}}^{pp} = 7$ TeV		
		334	10	AALTONEN	10K	CDF	$E_{\text{cm}}^{p\bar{p}} = 1.96$ TeV	
		53	11	AARON	09B	H1	$E_{\text{cm}}^{ep} = 0.3$ TeV	
1.07	$+0.26$ -0.29		12	ABAZOV	09AD	D0	$E_{\text{cm}}^{p\bar{p}} = 1.96$ TeV	
			13	ABAZOV	09AJ	D0	$E_{\text{cm}}^{p\bar{p}} = 1.96$ TeV	
			14	ABAZOV	08R	D0	$E_{\text{cm}}^{p\bar{p}} = 1.96$ TeV	
0.68	$+0.17$ -0.15	1880	15	ABDALLAH	08C	DLPH	Superseded by ABDALLAH 10	
		1617	16	AALTONEN	07L	CDF	$E_{\text{cm}}^{p\bar{p}} = 1.96$ GeV	
		17	17	ABAZOV	06H	D0	$E_{\text{cm}}^{p\bar{p}} = 1.96$ TeV	
		141	18	ABAZOV	05J	D0	$E_{\text{cm}}^{p\bar{p}} = 1.96$ TeV	
1.25	$+0.21$ -0.20	± 0.06	2298	19	ABREU	01i	DLPH	$E_{\text{cm}}^{ee} = 183+189$ GeV
				20	BREITWEG	00	ZEUS	$e^+p \rightarrow e^+W^\pm X$, $\sqrt{s} \approx 300$ GeV
0.92	± 0.34	331	21	ABBOTT	99i	D0	$E_{\text{cm}}^{p\bar{p}} = 1.8$ TeV	

¹ ABDALLAH 10 use data on the final states $e^+e^- \rightarrow jj\ell\nu, jjjj, jjX, \ell X$, at center-of-mass energies between 189–209 GeV at LEP2, where $j = \text{jet}$, $\ell = \text{lepton}$, and X represents missing momentum. The fit is carried out keeping all other parameters fixed at their SM values.

² SCHAEEL 05A study single-photon, single- W , and WW -pair production from 183 to 209 GeV. Each parameter is determined from a single-parameter fit in which the other parameters assume their Standard Model values.

³ ABBIENDI 04D combine results from W^+W^- in all decay channels. Only CP -conserving couplings are considered and each parameter is determined from a single-parameter fit in which the other parameters assume their Standard Model values. The 95% confidence interval is $0.73 < \kappa_\gamma < 1.07$.

⁴ ACHARD 04D study WW -pair production, single- W production and single-photon production with missing energy from 189 to 209 GeV. The result quoted here is obtained including data from 161 to 183 GeV, ACCIARRI 99Q. Each parameter is determined from a single-parameter fit in which the other parameters assume their Standard Model values.

⁵ AAD 13AN study $W\gamma$ production in pp collisions. In events with no additional jet, 4449 (6578) W decays to electron (muon) are selected, with an expected background of 1662 ± 262 (2538 ± 362) events. Analysing the photon p_T spectrum above 100 GeV yields a 95% C.L. limit of $0.59 < \kappa_\gamma < 1.46$. Supersedes AAD 12BX.

⁶ CHATRCHYAN 13BF determine the W^+W^- production cross section using unlike sign di-lepton (e or μ) events with high p_T . The leptons have $p_T > 20$ GeV/ c and are isolated. 1134 candidate events are observed with an expected SM background of 247 ± 34 . The p_T distribution of the leading lepton is fitted to obtain 95% C.L. limits of $0.79 \leq k_\gamma \leq 1.22$.

⁷ ABAZOV 12AG combine new results with already published results on $W\gamma$, WW and WZ production in order to determine the couplings with increased precision, superseding ABAZOV 08R, ABAZOV 11AC, ABAZOV 09AJ, ABAZOV 09AD. The 68% C.L. result for a formfactor cutoff of $\Lambda = 2$ TeV is $\kappa_\gamma = 1.048^{+0.106}_{-0.105}$.

⁸ ABAZOV 11AC study $W\gamma$ production in $p\bar{p}$ collisions at 1.96 TeV, with the W decay products containing an electron or a muon. They select 196 (363) events in the electron

- (muon) mode, with a SM expectation of 190 (372) events. A likelihood fit to the photon E_T spectrum above 15 GeV yields at 95% C.L. the result: $0.6 < \kappa_\gamma < 1.4$ for a formfactor $\Lambda = 2$ TeV.
- 9 CHATRCHYAN 11M study $W\gamma$ production in pp collisions at $\sqrt{s} = 7$ TeV using 36 pb^{-1} pp data with the W decaying to electron and muon. The total cross section is measured for photon transverse energy $E_T^\gamma > 10$ GeV and spatial separation from charged leptons in the plane of pseudo rapidity and azimuthal angle $\Delta R(\ell, \gamma) > 0.7$. The number of candidate (background) events is 452 (228 ± 21) for the electron channel and 520 (277 ± 25) for the muon channel. Setting other couplings to their standard model value, they derive a 95% CL limit of $-0.11 < \kappa_\gamma < 2.04$.
 - 10 AALTONEN 10K study $p\bar{p} \rightarrow W^+W^-$ with $W \rightarrow e/\mu\nu$. The p_T of the leading (second) lepton is required to be > 20 (10) GeV. The final number of events selected is 654 of which 320 ± 47 are estimated to be background. The 95% C.L. interval is $0.37 < \kappa_\gamma < 1.72$ for $\Lambda = 1.5$ TeV and $0.43 < \kappa_\gamma < 1.65$ for $\Lambda = 2$ TeV.
 - 11 AARON 09B study single- W production in $e p$ collisions at 0.3 TeV C.M. energy. They select 53 $W \rightarrow e/\mu$ events with a standard model expectation of 54.1 ± 7.4 events. Fitting the transverse momentum spectrum of the hadronic recoil system they obtain a 95% C.L. limit of $-3.7 < \kappa_\gamma < -1.5$ or $0.3 < \kappa_\gamma < 1.5$, where the ambiguity is due to the quadratic dependence of the cross section to the coupling parameter.
 - 12 ABAZOV 09AD study the $p\bar{p} \rightarrow \ell\nu 2\text{jet}$ process arising in WW and WZ production. They select 12,473 (14,392) events in the electron (muon) channel with an expected di-boson signal of 436 (527) events. The results on the anomalous couplings are derived from an analysis of the p_T spectrum of the 2-jet system and quoted at 68% C.L. and for a form factor of 2 TeV. This measurement is not used for obtaining the mean as it is for a specific form factor. The 95% confidence interval is $0.56 < \kappa_\gamma < 1.55$.
 - 13 ABAZOV 09AJ study the $p\bar{p} \rightarrow 2\ell 2\nu$ process arising in WW production. They select 100 events with an expected WW signal of 65 events. An analysis of the p_T spectrum of the two charged leptons leads to 95% C.L. limits of $0.46 < \kappa_\gamma < 1.83$, for a form factor $\Lambda = 2$ TeV.
 - 14 ABAZOV 08R use 0.7 fb^{-1} $p\bar{p}$ data at $\sqrt{s} = 1.96$ TeV to select 263 $W\gamma + X$ events, of which 187 constitute signal, with the W decaying into an electron or a muon, which is required to be well separated from a photon with $E_T > 9$ GeV. A likelihood fit to the photon E_T spectrum yields a 95% CL limit $0.49 < \kappa_\gamma < 1.51$ with other couplings fixed to their Standard Model values.
 - 15 ABDALLAH 08C determine this triple gauge coupling from the measurement of the spin density matrix elements in $e^+e^- \rightarrow W^+W^- \rightarrow (qq)(\ell\nu)$, where $\ell = e$ or μ . Values of all other couplings are fixed to their standard model values.
 - 16 AALTONEN 07L set limits on anomalous TGCs using the $p_T(W)$ distribution in WW and WZ production with the W decaying to an electron or muon and the Z to 2 jets. Setting other couplings to their standard model value, the 95% C.L. limits are $0.54 < \kappa_\gamma < 1.39$ for a form factor scale $\Lambda = 1.5$ TeV.
 - 17 ABAZOV 06H study $p\bar{p} \rightarrow WW$ production with a subsequent decay $WW \rightarrow e^+\nu_e e^-\bar{\nu}_e$, $WW \rightarrow e^\pm\nu_e\mu^\mp\nu_\mu$ or $WW \rightarrow \mu^+\nu_\mu\mu^-\bar{\nu}_\mu$. The 95% C.L. limit for a form factor scale $\Lambda = 1$ TeV is $-0.05 < \kappa_\gamma < 2.29$, fixing $\lambda_\gamma = 0$. With the assumption that the $WW\gamma$ and WWZ couplings are equal the 95% C.L. one-dimensional limit ($\Lambda = 2$ TeV) is $0.68 < \kappa < 1.45$.
 - 18 ABAZOV 05J perform a likelihood fit to the photon E_T spectrum of $W\gamma + X$ events, where the W decays to an electron or muon which is required to be well separated from the photon. For $\Lambda = 2.0$ TeV the 95% CL limits are $0.12 < \kappa_\gamma < 1.96$. In the fit λ_γ is kept fixed to its Standard Model value.
 - 19 ABREU 01I combine results from e^+e^- interactions at 189 GeV leading to W^+W^- , $W e\nu_e$, and $\nu\bar{\nu}\gamma$ final states with results from ABREU 99L at 183 GeV. The 95% confidence interval is $0.87 < \kappa_\gamma < 1.68$.

- ²⁰ BREITWEG 00 search for W production in events with large hadronic p_T . For $p_T > 20$ GeV, the upper limit on the cross section gives the 95%CL limit $-3.7 < \kappa_\gamma < 2.5$ (for $\lambda_\gamma = 0$).
- ²¹ ABBOTT 99I perform a simultaneous fit to the $W\gamma$, $WW \rightarrow$ dilepton, $WW/WZ \rightarrow e\nu jj$, $WW/WZ \rightarrow \mu\nu jj$, and $WZ \rightarrow$ trilepton data samples. For $\Lambda = 2.0$ TeV, the 95%CL limits are $0.75 < \kappa_\gamma < 1.39$.

λ_γ

OUR FIT below is taken from [SCHAEL 13A].

<u>VALUE</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
-0.022 ± 0.019 OUR FIT				
0.002 ± 0.035	7872	1 ABDALLAH	10 DLPH	$E_{cm}^{ee} = 189-209$ GeV
-0.012 ± 0.027 ± 0.011	10689	2 SCHAEL	05A ALEP	$E_{cm}^{ee} = 183-209$ GeV
-0.060 ^{+0.034} / _{-0.033}	9800	3 ABBIENDI	04D OPAL	$E_{cm}^{ee} = 183-209$ GeV
-0.021 ^{+0.035} / _{-0.034} ± 0.017	10575	4 ACHARD	04D L3	$E_{cm}^{ee} = 161-209$ GeV
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
		5 AAD	13AN ATLS	$E_{cm}^{pp} = 7$ TeV
		6 ABAZOV	12AG D0	$E_{cm}^{pp} = 1.96$ TeV
		7 ABAZOV	11AC D0	$E_{cm}^{pp} = 1.96$ TeV
		8 CHATRCHYAN	11M CMS	$E_{cm}^{pp} = 7$ TeV
	53	9 AARON	09B H1	$E_{cm}^{ep} = 0.3$ TeV
0.00 ± 0.06		10 ABAZOV	09AD D0	$E_{cm}^{pp} = 1.96$ TeV
		11 ABAZOV	09AJ D0	$E_{cm}^{pp} = 1.96$ TeV
		12 ABAZOV	08R D0	$E_{cm}^{pp} = 1.96$ TeV
0.16 ^{+0.12} / _{-0.13}	1880	13 ABDALLAH	08C DLPH	Superseded by ABDALLAH 10
	1617	14 AALTONEN	07L CDF	$E_{cm}^{pp} = 1.96$ GeV
	17	15 ABAZOV	06H D0	$E_{cm}^{pp} = 1.96$ TeV
	141	16 ABAZOV	05J D0	$E_{cm}^{pp} = 1.96$ TeV
0.05 ± 0.09 ± 0.01	2298	17 ABREU	01I DLPH	$E_{cm}^{ee} = 183+189$ GeV
		18 BREITWEG	00 ZEUS	$e^+ p \rightarrow e^+ W^\pm X$, $\sqrt{s} \approx 300$ GeV
0.00 ^{+0.10} / _{-0.09}	331	19 ABBOTT	99I D0	$E_{cm}^{pp} = 1.8$ TeV

¹ ABDALLAH 10 use data on the final states $e^+ e^- \rightarrow jj\ell\nu, jjjj, jjX, \ell X$, at center-of-mass energies between 189–209 GeV at LEP2, where $j =$ jet, $\ell =$ lepton, and X represents missing momentum. The fit is carried out keeping all other parameters fixed at their SM values.

² SCHAEL 05A study single-photon, single- W , and WW -pair production from 183 to 209 GeV. Each parameter is determined from a single-parameter fit in which the other parameters assume their Standard Model values.

³ ABBIENDI 04D combine results from $W^+ W^-$ in all decay channels. Only CP -conserving couplings are considered and each parameter is determined from a single-parameter fit in which the other parameters assume their Standard Model values. The 95% confidence interval is $-0.13 < \lambda_\gamma < 0.01$.

⁴ ACHARD 04D study WW -pair production, single- W production and single-photon production with missing energy from 189 to 209 GeV. The result quoted here is obtained

- including data from 161 to 183 GeV, ACCIARRI 99Q. Each parameter is determined from a single-parameter fit in which the other parameters assume their Standard Model values.
- 5 AAD 13AN study $W\gamma$ production in pp collisions. In events with no additional jet, 4449 (6578) W decays to electron (muon) are selected, with an expected background of 1662 ± 262 (2538 ± 362) events. Analysing the photon p_T spectrum above 100 GeV yields a 95% C.L. limit of $-0.065 < \lambda_\gamma < 0.061$. Supersedes AAD 12BX.
 - 6 ABAZOV 12AG combine new results with already published results on $W\gamma$, WW and WZ production in order to determine the couplings with increased precision, superseding ABAZOV 08R, ABAZOV 11AC, ABAZOV 09AJ, ABAZOV 09AD. The 68% C.L. result for a formfactor cutoff of $\Lambda = 2$ TeV is $\lambda_\gamma = 0.007^{+0.021}_{-0.022}$.
 - 7 ABAZOV 11AC study $W\gamma$ production in $p\bar{p}$ collisions at 1.96 TeV, with the W decay products containing an electron or a muon. They select 196 (363) events in the electron (muon) mode, with a SM expectation of 190 (372) events. A likelihood fit to the photon E_T spectrum above 15 GeV yields at 95% C.L. the result: $-0.08 < \lambda_\gamma < 0.07$ for a formfactor $\Lambda = 2$ TeV.
 - 8 CHATRCHYAN 11M study $W\gamma$ production in pp collisions at $\sqrt{s} = 7$ TeV using 36 pb^{-1} pp data with the W decaying to electron and muon. The total cross section is measured for photon transverse energy $E_T^\gamma > 10$ GeV and spatial separation from charged leptons in the plane of pseudo rapidity and azimuthal angle $\Delta R(\ell, \gamma) > 0.7$. The number of candidate (background) events is 452 (228 ± 21) for the electron channel and 520 (277 ± 25) for the muon channel. Setting other couplings to their standard model value, they derive a 95% CL limit of $-0.18 < \lambda_\gamma < 0.17$.
 - 9 AARON 09B study single- W production in $e p$ collisions at 0.3 TeV C.M. energy. They select 53 $W \rightarrow e/\mu$ events with a standard model expectation of 54.1 ± 7.4 events. Fitting the transverse momentum spectrum of the hadronic recoil system they obtain a 95% C.L. limit of $-2.5 < \lambda_\gamma < 2.5$.
 - 10 ABAZOV 09AD study the $p\bar{p} \rightarrow \ell\nu 2\text{jet}$ process arising in WW and WZ production. They select 12,473 (14,392) events in the electron (muon) channel with an expected di-boson signal of 436 (527) events. The results on the anomalous couplings are derived from an analysis of the p_T spectrum of the 2-jet system and quoted at 68% C.L. and for a form factor of 2 TeV. This measurement is not used for obtaining the mean as it is for a specific form factor. The 95% confidence interval is $-0.10 < \lambda_\gamma < 0.11$.
 - 11 ABAZOV 09AJ study the $p\bar{p} \rightarrow 2\ell 2\nu$ process arising in WW production. They select 100 events with an expected WW signal of 65 events. An analysis of the p_T spectrum of the two charged leptons leads to 95% C.L. limits of $-0.14 < \lambda_\gamma < 0.18$, for a form factor $\Lambda = 2$ TeV.
 - 12 ABAZOV 08R use 0.7 fb^{-1} $p\bar{p}$ data at $\sqrt{s} = 1.96$ TeV to select 263 $W\gamma + X$ events, of which 187 constitute signal, with the W decaying into an electron or a muon, which is required to be well separated from a photon with $E_T > 9$ GeV. A likelihood fit to the photon E_T spectrum yields a 95% CL limit $-0.12 < \lambda_\gamma < 0.13$ with other couplings fixed to their Standard Model values.
 - 13 ABDALLAH 08C determine this triple gauge coupling from the measurement of the spin density matrix elements in $e^+e^- \rightarrow W^+W^- \rightarrow (qq)(\ell\nu)$, where $\ell = e$ or μ . Values of all other couplings are fixed to their standard model values.
 - 14 AALTONEN 07L set limits on anomalous TGCs using the $p_T(W)$ distribution in WW and WZ production with the W decaying to an electron or muon and the Z to 2 jets. Setting other couplings to their standard model value, the 95% C.L. limits are $-0.18 < \lambda_\gamma < 0.17$ for a form factor scale $\Lambda = 1.5$ TeV.
 - 15 ABAZOV 06H study $p\bar{p} \rightarrow WW$ production with a subsequent decay $WW \rightarrow e^+\nu_e e^-\bar{\nu}_e$, $WW \rightarrow e^\pm\nu_e \mu^\mp\nu_\mu$ or $WW \rightarrow \mu^+\nu_\mu \mu^-\bar{\nu}_\mu$. The 95% C.L. limit for a form factor scale $\Lambda = 1$ TeV is $-0.97 < \lambda_\gamma < 1.04$, fixing $\kappa_\gamma=1$. With the assumption that the $WW\gamma$ and WWZ couplings are equal the 95% C.L. one-dimensional limit ($\Lambda = 2$ TeV) is $-0.29 < \lambda < 0.30$.

- ¹⁶ ABAZOV 05J perform a likelihood fit to the photon E_T spectrum of $W\gamma + X$ events, where the W decays to an electron or muon which is required to be well separated from the photon. For $\Lambda = 2.0$ TeV the 95% CL limits are $-0.20 < \lambda_\gamma < 0.20$. In the fit κ_γ is kept fixed to its Standard Model value.
- ¹⁷ ABREU 01I combine results from e^+e^- interactions at 189 GeV leading to W^+W^- , $W e \nu_e$, and $\nu \bar{\nu} \gamma$ final states with results from ABREU 99L at 183 GeV. The 95% confidence interval is $-0.11 < \lambda_\gamma < 0.23$.
- ¹⁸ BREITWEG 00 search for W production in events with large hadronic p_T . For $p_T > 20$ GeV, the upper limit on the cross section gives the 95%CL limit $-3.2 < \lambda_\gamma < 3.2$ for κ_γ fixed to its Standard Model value.
- ¹⁹ ABBOTT 99I perform a simultaneous fit to the $W\gamma$, $WW \rightarrow$ dilepton, $WW/WZ \rightarrow e\nu jj$, $WW/WZ \rightarrow \mu\nu jj$, and $WZ \rightarrow$ trilepton data samples. For $\Lambda = 2.0$ TeV, the 95%CL limits are $-0.18 < \lambda_\gamma < 0.19$.

κ_Z

This coupling is CP -conserving (C - and P - separately conserving).

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
$0.924^{+0.059}_{-0.056} \pm 0.024$	7171	¹ ACHARD	04D L3	$E_{cm}^{ee} = 189\text{--}209$ GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
		² AAD	13AL ATLS	$E_{cm}^{pp} = 7$ TeV
		³ AAD	12CD ATLS	$E_{cm}^{pp} = 7$ TeV
		⁴ AALTONEN	12AC CDF	$E_{cm}^{p\bar{p}} = 1.96$ TeV
	34	⁵ ABAZOV	11 D0	$E_{cm}^{p\bar{p}} = 1.96$ TeV
	17	⁶ ABAZOV	06H D0	$E_{cm}^{p\bar{p}} = 1.96$ TeV
	2.3	⁷ ABAZOV	05S D0	$E_{cm}^{p\bar{p}} = 1.96$ TeV

- ¹ ACHARD 04D study WW -pair production, single- W production and single-photon production with missing energy from 189 to 209 GeV. The result quoted here is obtained using the WW -pair production sample. Each parameter is determined from a single-parameter fit in which the other parameters assume their Standard Model values.
- ² AAD 13AL study WW production in pp collisions and select 1325 WW candidates in decay modes with electrons or muons with an expected background of 369 ± 61 events. Assuming the LEP formulation and setting the form-factor $\Lambda =$ infinity, a fit to the transverse momentum distribution of the leading charged lepton, leads to a 95% C.L. range of $0.957 < \kappa_Z < 1.043$. Supersedes AAD 12AC.
- ³ AAD 12CD study WZ production in pp collisions and select 317 WZ candidates in three $\ell\nu$ decay modes with an expected background of 68.0 ± 10.0 events. The resulting 95% C.L. range is: $0.63 < \kappa_Z < 1.57$. Supersedes AAD 12V.
- ⁴ AALTONEN 12AC study WZ production in $p\bar{p}$ collisions and select 63 WZ candidates in three $\ell\nu$ decay modes with an expected background of 7.9 ± 1.0 events. Based on the cross section and shape of the Z transverse momentum spectrum, the following 95% C.L. range is reported: $0.61 < \kappa_Z < 1.90$ for a form factor of $\Lambda = 2$ TeV.
- ⁵ ABAZOV 11 study the $p\bar{p} \rightarrow 3\ell\nu$ process arising in WZ production. They observe 34 WZ candidates with an estimated background of 6 events. An analysis of the p_T spectrum of the Z boson leads to a 95% C.L. limit of $0.600 < \kappa_Z < 1.675$, for a form factor $\Lambda = 2$ TeV.
- ⁶ ABAZOV 06H study $\bar{p}p \rightarrow WW$ production with a subsequent decay $WW \rightarrow e^+\nu_e e^-\bar{\nu}_e$, $WW \rightarrow e^\pm\nu_e \mu^\mp\nu_\mu$ or $WW \rightarrow \mu^+\nu_\mu \mu^-\bar{\nu}_\mu$. The 95% C.L. limit for a form factor scale $\Lambda = 2$ TeV is $0.55 < \kappa_Z < 1.55$, fixing $\lambda_Z = 0$. With the assumption that the $WW\gamma$ and WWZ couplings are equal the 95% C.L. one-dimensional limit ($\Lambda = 2$ TeV) is $0.68 < \kappa < 1.45$.

⁷ ABAZOV 05S study $\bar{p}p \rightarrow WZ$ production with a subsequent tripleton decay to $\ell\nu\ell'\bar{\ell}'$ (ℓ and $\ell' = e$ or μ). Three events (estimated background 0.71 ± 0.08 events) with WZ decay characteristics are observed from which they derive limits on the anomalous WWZ couplings. The 95% CL limit for a form factor scale $\Lambda = 1$ TeV is $-1.0 < \kappa_Z < 3.4$, fixing λ_Z and g_1^Z to their Standard Model values.

λ_Z

This coupling is CP -conserving (C - and P - separately conserving).

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
$-0.088^{+0.060}_{-0.057} \pm 0.023$	7171	¹ ACHARD	04D L3	$E_{cm}^{ee} = 189\text{--}209$ GeV
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
		² AAD	13AL ATLS	$E_{cm}^{pp} = 7$ TeV
		³ CHATRCHYAN	13BF CMS	$E_{cm}^{pp} = 7$ TeV
		⁴ AAD	12CD ATLS	$E_{cm}^{pp} = 7$ TeV
		⁵ AALTONEN	12AC CDF	$E_{cm}^{pp} = 1.96$ TeV
	34	⁶ ABAZOV	11 D0	$E_{cm}^{pp} = 1.96$ TeV
	334	⁷ AALTONEN	10K CDF	$E_{cm}^{pp} = 1.96$ TeV
	13	⁸ ABAZOV	07Z D0	$E_{cm}^{pp} = 1.96$ TeV
	17	⁹ ABAZOV	06H D0	$E_{cm}^{pp} = 1.96$ TeV
	2.3	¹⁰ ABAZOV	05S D0	$E_{cm}^{pp} = 1.96$ TeV

¹ ACHARD 04D study WW -pair production, single- W production and single-photon production with missing energy from 189 to 209 GeV. The result quoted here is obtained using the WW -pair production sample. Each parameter is determined from a single-parameter fit in which the other parameters assume their Standard Model values.

² AAD 13AL study WW production in pp collisions and select 1325 WW candidates in decay modes with electrons or muons with an expected background of 369 ± 61 events. Assuming the LEP formulation and setting the form-factor $\Lambda = \text{infinity}$, a fit to the transverse momentum distribution of the leading charged lepton, leads to a 95% C.L. range of $-0.062 < \lambda_Z < 0.059$. Supersedes AAD 12AC.

³ CHATRCHYAN 13BF determine the W^+W^- production cross section using unlike sign di-lepton (e or μ) events with high p_T . The leptons have $p_T > 20$ GeV/c and are isolated. 1134 candidate events are observed with an expected SM background of 247 ± 34 . The p_T distribution of the leading lepton is fitted to obtain 95% C.L. limits of $-0.048 \leq \lambda_Z \leq 0.048$.

⁴ AAD 12CD study WZ production in pp collisions and select 317 WZ candidates in three $\ell\nu$ decay modes with an expected background of 68.0 ± 10.0 events. The resulting 95% C.L. range is: $-0.046 < \lambda_Z < 0.047$. Supersedes AAD 12V.

⁵ AALTONEN 12AC study WZ production in $p\bar{p}$ collisions and select 63 WZ candidates in three $\ell\nu$ decay modes with an expected background of 7.9 ± 1.0 events. Based on the cross section and shape of the Z transverse momentum spectrum, the following 95% C.L. range is reported: $-0.08 < \lambda_Z < 0.10$ for a form factor of $\Lambda = 2$ TeV.

⁶ ABAZOV 11 study the $p\bar{p} \rightarrow 3\ell\nu$ process arising in WZ production. They observe 34 WZ candidates with an estimated background of 6 events. An analysis of the p_T spectrum of the Z boson leads to a 95% C.L. limit of $-0.077 < \lambda_Z < 0.093$, for a form factor $\Lambda = 2$ TeV.

⁷ AALTONEN 10K study $p\bar{p} \rightarrow W^+W^-$ with $W \rightarrow e/\mu\nu$. The p_T of the leading (second) lepton is required to be > 20 (10) GeV. The final number of events selected is 654 of which 320 ± 47 are estimated to be background. The 95% C.L. interval is $-0.16 < \lambda_Z < 0.16$ for $\Lambda = 1.5$ TeV and $-0.14 < \lambda_Z < 0.15$ for $\Lambda = 2$ TeV.

⁸ ABAZOV 07Z set limits on anomalous TGCs using the measured cross section and $p_T(Z)$ distribution in WZ production with both the W and the Z decaying leptonically into electrons and muons. Setting the other couplings to their standard model values, the 95% C.L. limit for a form factor scale $\Lambda = 2$ TeV is $-0.17 < \lambda_Z < 0.21$.

⁹ ABAZOV 06H study $\bar{p}p \rightarrow WW$ production with a subsequent decay $WW \rightarrow e^+ \nu_e e^- \bar{\nu}_e$, $WW \rightarrow e^\pm \nu_e \mu^\mp \nu_\mu$ or $WW \rightarrow \mu^+ \nu_\mu \mu^- \bar{\nu}_\mu$. The 95% C.L. limit for a form factor scale $\Lambda = 2$ TeV is $-0.39 < \lambda_Z < 0.39$, fixing $\kappa_Z=1$. With the assumption that the $W\gamma$ and WWZ couplings are equal the 95% C.L. one-dimensional limit ($\Lambda = 2$ TeV) is $-0.29 < \lambda < 0.30$.

¹⁰ ABAZOV 05S study $\bar{p}p \rightarrow WZ$ production with a subsequent triplepton decay to $\ell\nu\ell'\bar{\ell}'$ (ℓ and $\ell' = e$ or μ). Three events (estimated background 0.71 ± 0.08 events) with WZ decay characteristics are observed from which they derive limits on the anomalous WWZ couplings. The 95% CL limit for a form factor scale $\Lambda = 1.5$ TeV is $-0.48 < \lambda_Z < 0.48$, fixing g_1^Z and κ_Z to their Standard Model values.

g_5^Z

This coupling is CP -conserving but C - and P -violating.

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
-0.07 ± 0.09 OUR AVERAGE		Error includes scale factor of 1.1.		
$-0.04^{+0.13}_{-0.12}$	9800	¹ ABBIENDI	04D OPAL	$E_{cm}^{ee} = 183-209$ GeV
$0.00 \pm 0.13 \pm 0.05$	7171	² ACHARD	04D L3	$E_{cm}^{ee} = 189-209$ GeV
$-0.44^{+0.23}_{-0.22} \pm 0.12$	1154	³ ACCIARRI	99Q L3	$E_{cm}^{ee} = 161+172+ 183$ GeV
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
-0.31 ± 0.23		⁴ EBOLI	00 THEO	LEP1, SLC+ Tevatron

¹ ABBIENDI 04D combine results from W^+W^- in all decay channels. Only CP -conserving couplings are considered and each parameter is determined from a single-parameter fit in which the other parameters assume their Standard Model values. The 95% confidence interval is $-0.28 < g_5^Z < +0.21$.

² ACHARD 04D study WW -pair production, single- W production and single-photon production with missing energy from 189 to 209 GeV. The result quoted here is obtained using the WW -pair production sample. Each parameter is determined from a single-parameter fit in which the other parameters assume their Standard Model values.

³ ACCIARRI 99Q study W -pair, single- W , and single photon events.

⁴ EBOLI 00 extract this indirect value of the coupling studying the non-universal one-loop contributions to the experimental value of the $Z \rightarrow b\bar{b}$ width ($\Lambda=1$ TeV is assumed).

g_4^Z

This coupling is CP -violating (C -violating and P -conserving).

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
-0.30 ± 0.17 OUR AVERAGE				
$-0.39^{+0.19}_{-0.20}$	1880	¹ ABDALLAH	08C DLPH	$E_{cm}^{ee} = 189-209$ GeV
$-0.02^{+0.32}_{-0.33}$	1065	² ABBIENDI	01H OPAL	$E_{cm}^{ee} = 189$ GeV

¹ ABDALLAH 08C determine this triple gauge coupling from the measurement of the spin density matrix elements in $e^+e^- \rightarrow W^+W^- \rightarrow (qq)(\ell\nu)$, where $\ell = e$ or μ . Values of all other couplings are fixed to their standard model values.

² ABBIENDI 01H study W -pair events, with one leptonically and one hadronically decaying W . The coupling is extracted using information from the W production angle together with decay angles from the leptonically decaying W .

$\tilde{\kappa}_Z$

This coupling is *CP*-violating (*C*-conserving and *P*-violating).

<u>VALUE</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
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$-0.12^{+0.06}_{-0.04}$ OUR AVERAGE

$-0.09^{+0.08}_{-0.05}$	1880	¹ ABDALLAH	08C DLPH	$E_{\text{cm}}^{ee} = 189\text{--}209$ GeV
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$-0.20^{+0.10}_{-0.07}$	1065	² ABBIENDI	01H OPAL	$E_{\text{cm}}^{ee} = 189$ GeV
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• • • We do not use the following data for averages, fits, limits, etc. • • •

		³ BLINOV	11 LEP	$E_{\text{cm}}^{ee} = 183\text{--}207$ GeV
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¹ ABDALLAH 08C determine this triple gauge coupling from the measurement of the spin density matrix elements in $e^+e^- \rightarrow W^+W^- \rightarrow (qq)(\ell\nu)$, where $\ell = e$ or μ . Values of all other couplings are fixed to their standard model values.

² ABBIENDI 01H study *W*-pair events, with one leptonically and one hadronically decaying *W*. The coupling is extracted using information from the *W* production angle together with decay angles from the leptonically decaying *W*.

³ BLINOV 11 use the LEP-average $e^+e^- \rightarrow W^+W^-$ cross section data for $\sqrt{s} = 183\text{--}207$ GeV to determine an upper limit on the TGC $\tilde{\kappa}_Z$. The average values of the cross sections as well as their correlation matrix, and standard model expectations of the cross sections are taken from the LEPEWWG note hep-ex/0612034. At 95% confidence level $|\tilde{\kappa}_Z| < 0.13$.

$\tilde{\lambda}_Z$

This coupling is *CP*-violating (*C*-conserving and *P*-violating).

<u>VALUE</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
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-0.09 ± 0.07 OUR AVERAGE

-0.08 ± 0.07	1880	¹ ABDALLAH	08C DLPH	$E_{\text{cm}}^{ee} = 189\text{--}209$ GeV
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$-0.18^{+0.24}_{-0.16}$	1065	² ABBIENDI	01H OPAL	$E_{\text{cm}}^{ee} = 189$ GeV
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• • • We do not use the following data for averages, fits, limits, etc. • • •

		³ BLINOV	11 LEP	$E_{\text{cm}}^{ee} = 183\text{--}207$ GeV
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¹ ABDALLAH 08C determine this triple gauge coupling from the measurement of the spin density matrix elements in $e^+e^- \rightarrow W^+W^- \rightarrow (qq)(\ell\nu)$, where $\ell = e$ or μ . Values of all other couplings are fixed to their standard model values.

² ABBIENDI 01H study *W*-pair events, with one leptonically and one hadronically decaying *W*. The coupling is extracted using information from the *W* production angle together with decay angles from the leptonically decaying *W*.

³ BLINOV 11 use the LEP-average $e^+e^- \rightarrow W^+W^-$ cross section data for $\sqrt{s} = 183\text{--}207$ GeV to determine an upper limit on the TGC $\tilde{\lambda}_Z$. The average values of the cross sections as well as their correlation matrix, and standard model expectations of the cross sections are taken from the LEPEWWG note hep-ex/0612034. At 95% confidence level $|\tilde{\lambda}_Z| < 0.31$.

W ANOMALOUS MAGNETIC MOMENT

The full magnetic moment is given by $\mu_W = e(1+\kappa + \lambda)/2m_W$. In the Standard Model, at tree level, $\kappa = 1$ and $\lambda = 0$. Some papers have defined $\Delta\kappa = 1-\kappa$ and assume that $\lambda = 0$. Note that the electric quadrupole moment is given by $-e(\kappa-\lambda)/m_W^2$. A description of the parameterization of these moments and additional references can be found in HAGIWARA 87 and BAUR 88. The parameter Λ appearing in the theoretical limits below is a regularization cutoff which roughly corresponds to the energy scale where the structure of the W boson becomes manifest.

<u>VALUE ($e/2m_W$)</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
2.22^{+0.20}_{-0.19}	2298	1 ABREU	01l DLPH	$E_{cm}^{ee} = 183+189$ GeV
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
		2 ABE	95G CDF	
		3 ALITTI	92C UA2	
		4 SAMUEL	92 THEO	
		5 SAMUEL	91 THEO	
		6 GRIFOLS	88 THEO	
		7 GROTCHE	87 THEO	
		8 VANDERBIJ	87 THEO	
		9 GRAU	85 THEO	
		10 SUZUKI	85 THEO	
		11 HERZOG	84 THEO	

¹ ABREU 01l combine results from e^+e^- interactions at 189 GeV leading to W^+W^- , $W e \nu_e$, and $\nu \bar{\nu} \gamma$ final states with results from ABREU 99L at 183 GeV to determine Δg_1^Z , $\Delta\kappa_\gamma$, and λ_γ . $\Delta\kappa_\gamma$ and λ_γ are simultaneously floated in the fit to determine μ_W .

² ABE 95G report $-1.3 < \kappa < 3.2$ for $\lambda=0$ and $-0.7 < \lambda < 0.7$ for $\kappa=1$ in $p\bar{p} \rightarrow e\nu_e\gamma X$ and $\mu\nu_\mu\gamma X$ at $\sqrt{s} = 1.8$ TeV.

³ ALITTI 92C measure $\kappa = 1^{+2.6}_{-2.2}$ and $\lambda = 0^{+1.7}_{-1.8}$ in $p\bar{p} \rightarrow e\nu\gamma + X$ at $\sqrt{s} = 630$ GeV. At 95%CL they report $-3.5 < \kappa < 5.9$ and $-3.6 < \lambda < 3.5$.

⁴ SAMUEL 92 use preliminary CDF and UA2 data and find $-2.4 < \kappa < 3.7$ at 96%CL and $-3.1 < \kappa < 4.2$ at 95%CL respectively. They use data for $W\gamma$ production and radiative W decay.

⁵ SAMUEL 91 use preliminary CDF data for $p\bar{p} \rightarrow W\gamma X$ to obtain $-11.3 \leq \Delta\kappa \leq 10.9$. Note that their $\kappa = 1 - \Delta\kappa$.

⁶ GRIFOLS 88 uses deviation from ρ parameter to set limit $\Delta\kappa \lesssim 65 (M_W^2/\Lambda^2)$.

⁷ GROTCHE 87 finds the limit $-37 < \Delta\kappa < 73.5$ (90% CL) from the experimental limits on $e^+e^- \rightarrow \nu\bar{\nu}\gamma$ assuming three neutrino generations and $-19.5 < \Delta\kappa < 56$ for four generations. Note their $\Delta\kappa$ has the opposite sign as our definition.

⁸ VANDERBIJ 87 uses existing limits to the photon structure to obtain $|\Delta\kappa| < 33 (m_W/\Lambda)$. In addition VANDERBIJ 87 discusses problems with using the ρ parameter of the Standard Model to determine $\Delta\kappa$.

⁹ GRAU 85 uses the muon anomaly to derive a coupled limit on the anomalous magnetic dipole and electric quadrupole (λ) moments $1.05 > \Delta\kappa \ln(\Lambda/m_W) + \lambda/2 > -2.77$. In the Standard Model $\lambda = 0$.

¹⁰ SUZUKI 85 uses partial-wave unitarity at high energies to obtain $|\Delta\kappa| \lesssim 190 (m_W/\Lambda)^2$. From the anomalous magnetic moment of the muon, SUZUKI 85 obtains $|\Delta\kappa| \lesssim 2.2/\ln(\Lambda/m_W)$. Finally SUZUKI 85 uses deviations from the ρ parameter and obtains a very qualitative, order-of-magnitude limit $|\Delta\kappa| \lesssim 150 (m_W/\Lambda)^4$ if $|\Delta\kappa| \ll 1$.

¹¹HERZOG 84 consider the contribution of W -boson to muon magnetic moment including anomalous coupling of $W W \gamma$. Obtain a limit $-1 < \Delta\kappa < 3$ for $\Lambda \gtrsim 1$ TeV.

ANOMALOUS W/Z QUARTIC COUPLINGS

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a_0/Λ^2 , a_c/Λ^2 , a_n/Λ^2

Using the $W W \gamma$ final state, the LEP combined 95% CL limits on the anomalous contributions to the $W W \gamma \gamma$ and $W W Z \gamma$ vertices (as of summer 2003) are given below:

(See P. Wells, “Experimental Tests of the Standard Model,” Int. Europhysics Conference on High-Energy Physics, Aachen, Germany, 17–23 July 2003)

$$\begin{aligned} -0.02 < a_0^W/\Lambda^2 < 0.02 \text{ GeV}^{-2}, \\ -0.05 < a_c^W/\Lambda^2 < 0.03 \text{ GeV}^{-2}, \\ -0.15 < a_n/\Lambda^2 < 0.15 \text{ GeV}^{-2}. \end{aligned}$$

VALUE	DOCUMENT ID	TECN
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• • • We do not use the following data for averages, fits, limits, etc. • • •

1	ABAZOV	13D	D0
2	CHATRCHYAN	13AA	CMS
3	ABBIENDI	04B	OPAL
4	ABBIENDI	04L	OPAL
5	HEISTER	04A	ALEP
6	ABDALLAH	03I	DLPH
7	ACHARD	02F	L3

¹ABAZOV 13D searches for anomalous $W W \gamma \gamma$ quartic gauge couplings in the two-photon-mediated process $pp \rightarrow pp W W$, assuming the $W W \gamma$ triple gauge boson couplings to be at their Standard Model values. 946 events containing an $e^+ e^-$ pair with missing energy are selected in a total luminosity of 9.7 fb^{-1} , with an expectation of 983 ± 108 events from Standard-Model processes. The following 1-parameter limits at 95% CL are obtained: $|a_0^W/\Lambda^2| < 4.3 \times 10^{-4} \text{ GeV}^{-2}$ ($a_c^W = 0$), $|a_c^W/\Lambda^2| < 1.5 \times 10^{-3} \text{ GeV}^{-2}$ ($a_0^W = 0$).

²CHATRCHYAN 13AA searches for anomalous $W W \gamma \gamma$ quartic gauge couplings in the two-photon-mediated process $pp \rightarrow pp W W$, assuming the $W W \gamma$ triple gauge boson couplings to be at their Standard Model values. 2 events containing an $e^\pm \mu^\mp$ pair with $p_T(e, \mu) > 30 \text{ GeV}$ are selected in a total luminosity of 5.05 fb^{-1} , with an expected $pp W W$ signal of 2.2 ± 0.4 events and an expected background of 0.84 ± 0.15 events. The following 1-parameter limits at 95% CL are obtained from the $p_T(e, \mu)$ spectrum: $|a_0^W/\Lambda^2| < 4.0 \times 10^{-6} \text{ GeV}^{-2}$ ($a_c^W = 0$), $|a_c^W/\Lambda^2| < 1.5 \times 10^{-5} \text{ GeV}^{-2}$ ($a_0^W = 0$).

³ABBIENDI 04B select 187 $e^+ e^- \rightarrow W^+ W^- \gamma$ events in the C.M. energy range 180–209 GeV, where $E_\gamma > 2.5 \text{ GeV}$, the photon has a polar angle $|\cos\theta_\gamma| < 0.975$ and is well isolated from the nearest jet and charged lepton, and the effective masses of both fermion-antifermion systems agree with the W mass within $3 \Gamma_W$. The measured differential cross section as a function of the photon energy and photon polar angle is used to extract the 95% CL limits: $-0.020 \text{ GeV}^{-2} < a_0/\Lambda^2 < 0.020 \text{ GeV}^{-2}$, $-0.053 \text{ GeV}^{-2} < a_c/\Lambda^2 < 0.037 \text{ GeV}^{-2}$ and $-0.16 \text{ GeV}^{-2} < a_n/\Lambda^2 < 0.15 \text{ GeV}^{-2}$.

- ⁴ ABBIENDI 04L select 20 $e^+e^- \rightarrow \nu\bar{\nu}\gamma\gamma$ acoplanar events in the energy range 180–209 GeV and 176 $e^+e^- \rightarrow q\bar{q}\gamma\gamma$ events in the energy range 130–209 GeV. These samples are used to constrain possible anomalous $W^+W^-\gamma\gamma$ and $ZZ\gamma\gamma$ quartic couplings. Further combining with the $W^+W^-\gamma$ sample of ABBIENDI 04B the following one-parameter 95% CL limits are obtained: $-0.007 < a_0^Z/\Lambda^2 < 0.023 \text{ GeV}^{-2}$, $-0.029 < a_c^Z/\Lambda^2 < 0.029 \text{ GeV}^{-2}$, $-0.020 < a_0^W/\Lambda^2 < 0.020 \text{ GeV}^{-2}$, $-0.052 < a_c^W/\Lambda^2 < 0.037 \text{ GeV}^{-2}$.
- ⁵ In the CM energy range 183 to 209 GeV HEISTER 04A select 30 $e^+e^- \rightarrow \nu\bar{\nu}\gamma\gamma$ events with two acoplanar, high energy and high transverse momentum photons. The photon-photon acoplanarity is required to be $> 5^\circ$, $E_\gamma/\sqrt{s} > 0.025$ (the more energetic photon having energy $> 0.2\sqrt{s}$), $p_{T_\gamma}/E_{\text{beam}} > 0.05$ and $|\cos\theta_\gamma| < 0.94$. A likelihood fit to the photon energy and recoil missing mass yields the following one-parameter 95% CL limits: $-0.012 < a_0^Z/\Lambda^2 < 0.019 \text{ GeV}^{-2}$, $-0.041 < a_c^Z/\Lambda^2 < 0.044 \text{ GeV}^{-2}$, $-0.060 < a_0^W/\Lambda^2 < 0.055 \text{ GeV}^{-2}$, $-0.099 < a_c^W/\Lambda^2 < 0.093 \text{ GeV}^{-2}$.
- ⁶ ABDALLAH 03I select 122 $e^+e^- \rightarrow W^+W^-\gamma$ events in the C.M. energy range 189–209 GeV, where $E_\gamma > 5 \text{ GeV}$, the photon has a polar angle $|\cos\theta_\gamma| < 0.95$ and is well isolated from the nearest charged fermion. A fit to the photon energy spectra yields $a_c/\Lambda^2 = 0.000^{+0.019}_{-0.040} \text{ GeV}^{-2}$, $a_0/\Lambda^2 = -0.004^{+0.018}_{-0.010} \text{ GeV}^{-2}$, $\tilde{a}_0/\Lambda^2 = -0.007^{+0.019}_{-0.008} \text{ GeV}^{-2}$, $a_n/\Lambda^2 = -0.09^{+0.16}_{-0.05} \text{ GeV}^{-2}$, and $\tilde{a}_n/\Lambda^2 = +0.05^{+0.07}_{-0.15} \text{ GeV}^{-2}$, keeping the other parameters fixed to their Standard Model values (0). The 95% CL limits are: $-0.063 \text{ GeV}^{-2} < a_c/\Lambda^2 < +0.032 \text{ GeV}^{-2}$, $-0.020 \text{ GeV}^{-2} < a_0/\Lambda^2 < +0.020 \text{ GeV}^{-2}$, $-0.020 \text{ GeV}^{-2} < \tilde{a}_0/\Lambda^2 < +0.020 \text{ GeV}^{-2}$, $-0.18 \text{ GeV}^{-2} < a_n/\Lambda^2 < +0.14 \text{ GeV}^{-2}$, $-0.16 \text{ GeV}^{-2} < \tilde{a}_n/\Lambda^2 < +0.17 \text{ GeV}^{-2}$.
- ⁷ ACHARD 02F select 86 $e^+e^- \rightarrow W^+W^-\gamma$ events at 192–207 GeV, where $E_\gamma > 5 \text{ GeV}$ and the photon is well isolated. They also select 43 acoplanar $e^+e^- \rightarrow \nu\bar{\nu}\gamma\gamma$ events in this energy range, where the photon energies are $> 5 \text{ GeV}$ and $> 1 \text{ GeV}$ and the photon polar angles are between 14° and 166° . All these 43 events are in the recoil mass region corresponding to the Z (75–110 GeV). Using the shape and normalization of the photon spectra in the $W^+W^-\gamma$ events, and combining with the 42 event sample from 189 GeV data (ACCIARRI 00T), they obtain: $a_0/\Lambda^2 = 0.000 \pm 0.010 \text{ GeV}^{-2}$, $a_c/\Lambda^2 = -0.013 \pm 0.023 \text{ GeV}^{-2}$, and $a_n/\Lambda^2 = -0.002 \pm 0.076 \text{ GeV}^{-2}$. Further combining the analyses of $W^+W^-\gamma$ events with the low recoil mass region of $\nu\bar{\nu}\gamma\gamma$ events (including samples collected at 183 + 189 GeV), they obtain the following one-parameter 95% CL limits: $-0.015 \text{ GeV}^{-2} < a_0/\Lambda^2 < 0.015 \text{ GeV}^{-2}$, $-0.048 \text{ GeV}^{-2} < a_c/\Lambda^2 < 0.026 \text{ GeV}^{-2}$, and $-0.14 \text{ GeV}^{-2} < a_n/\Lambda^2 < 0.13 \text{ GeV}^{-2}$.

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